Fabrication and Performance of a Glue-Pressed Engineered Honeycomb Bamboo (GPEHB) Structure with Finger-jointed Ends as a Potential Substitute for Wood Lumber

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With the increasing scarcity of wood as a natural resource, bamboo has become a popular substitute for wood. The present work developed a high-strength original state multi-reorganization material (GPEHB), without the use of a hot press or traditional assembly. The original bamboo units were polygonized into outer contours and milled into finger-joints on each ending. The GPEHB was organized and assembled under an external press, using industrial adhesives. The mechanical properties and thermal insulation of GPEHB were characterized. Moreover, the overall GPEHB unit bending strength was 73.15 MPa, and the parallel-to-grain compression was 55.22 MPa (higher than that of *Pinus sylvestris* lumber, though less than that of glued laminated bamboo). The GPEHB unit overall density was 0.24 g/cm³, 76% lower than that of glued laminated bamboo, and 50% lower than *Pinus sylvestris* lumber. The compressive strength of GPEHB (7 units) was 170.5 kN, while the compressive strength of GPEHB for 14 units was 493.5 kN, which meet the requirements of GB 50005 (2003). The bending strength of GPEHB 7 units was 12 kN, while that of 14 units was 37 kN. The heat conductivity coefficient for GPEHB was 0.25 W/mK, which is better than concrete and steel. The GPEHB has taken full advantage of its honeycomb-structured material, which allows it to avoid stress concentration in the regular polygonal corners.

Keywords: Bamboo; Bionic fabrication; Original state reorganization; Mechanical properties; Heat-conducting performance

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INTRODUCTION

As the world supply of timber becomes increasingly scarce, the need to develop more rational and effective ways to utilize timber resources grows more urgent (Jiang *et al.* 2013). China has the most abundant supply of bamboo resources in the world. The current applications of bamboo materials range from flooring, furniture, and decorative crafts, to structural support in modern buildings (Zhang and Du 2007; Vogtlander *et al.* 2010; Li *et al.* 2011). It is widely believed that bamboo is one of the most promising alternatives to traditional wood materials in many fields.

Because of the limited resource distribution of bamboo, most studies and utilizations involving bamboo are primarily located in Asian countries. Thailand and India are also large producers of industrial bamboo, where bamboo is primarily used to produce paper or bamboo-reinforced concrete as structural units for buildings (Vogtlander *et al.* 2010). Furthermore, despite their limited production scale, Indonesia and Japan have conducted several studies on reconsolidated bamboo (Nugroho and Ando 2000; 2001; Serrano and Enquist 2005; Fu *et al.* 2007; Ma 2009; Vogtlander *et al.* 2010; Shiji *et al.* 2007; Sun *et al*. 2011). Since China introduced reconsolidated wood from Australia, many Chinese research institutes have attempted to manufacture reconsolidated wood and bamboo materials. Recently, reconsolidated bamboo floors manufactured in China have become best sellers in the domestic and foreign markets, with an annual output value in the tens billions Yuan (Yao 2010; Chen *et al*. 2013).

Conventionally, the existing bamboo recombinant units mainly are bamboo strips, chips, and fibers. In strip recombinant, arc-shaped bamboo strips are cut into several square bars, which is inefficient in regards to the utilization of raw materials. In chip recombinant, the intention is to improve utilization of raw materials, and the bamboo segments are shaped into small particles and chips by mechanical crushing. However, the natural grain typically gets severely destroyed, which consequently leads to a reduction mechanical properties of recombinant materials. For fiber recombinants, bamboo is processed into fiber bundles, which are subsequently made into boards with hot pressed resin-impregnated strips. However, the resulting panel has a coarse surface due to an uneven distribution of the fiber bundles. Furthermore, the recombinant bamboo material is primarily composed of small-sized units; as a consequence it does not meet the requirements of large-scale structural material for modern buildings (Qin and Yu 2009; Hohe and Becker 2000; Andrews *et al*. 2001; Li *et al*.2007).

The present research resulted in the development of a high-strength original state multi-reorganization material, without traditional assembly or the use of a hot press. The GPEHB takes full advantage of the honeycomb material structure, which allows for better avoidance of stress concentration in the regular polygonal corners. The mechanical properties and thermal insulation of GPEHB were characterized in this study. Another goal of the work was to determine whether superior properties could be achieved by imparting a regular hexagonal cross-section to the bamboo elements, allowing them to be glued together by pressure at ambient temperature, and furthermore joined together at their ends by finger-jointing in order to achieve the length required for the anticipated applications

EXPERIMENTAL

Materials

Four- to five-year-old moso bamboo (*Phyllostachys edulis*) was harvested from a bamboo research base in Xiangtan, Hunan province of China. The bamboo had a diameter of 80 to 100 mm and a wall thickness of 7.5 to 10 mm.

Adhesive for PVA was supplied by Jiangmen Dingshi Adhesive Industry Co., Ltd. (China). The adhesive had a solid content of 55%, viscosity of 200,000 mpa.s, density of 1.09 g/cm^3, and pH value of 6 to 7.

Sodium chloride (0.8%), acetic acid (1%), alum (41.5%), and polyethylene glycol (30%) were provided by the Beijing Industrial Salt Co., Ltd., Celanese (Nanjing) Chemical Co., Ltd., Hengyang Jianheng Industry Development Co., Ltd. (China), and Sinopec Shanghai Petrochemical Co. Ltd. (China), respectively. The chemicals were used as received.

Methods

Manufacturing of GPEHB

The original bamboo units were milled into the regular hexagon cross-sections of controlled dimension on their outer contours, and then milled into finger-joints on each end. Either the partial side plane or all side plane on the bamboo's external surface was coated with adhesive layers, through which the sides of several bamboo units were able to bind together to form side-to-side multi-hole arrangements, which extend horizontally infinitely.

The joint surface of the mortise joint structure at the end of polygonized bamboo unit was coated with an adhesive layer, through which one or two ends of the bamboo units bind together to vertically extend infinitely (Fu *et al.* 2011).

The basic fabrication procedure for GPEHB includes the chemical pretreatment of bamboo, regular polygon milling, horizontal bionic extending, assembling and gluing, and pressing. The specific manufacturing involved the following sequence of steps: crosscutting → boiling → filling → drying → regular polygon milling → finger joint milling → gluing → longitudinal joining → gluing → horizontal bionic molding → solidifying.

It is necessary to remove the nodes from the process. Such removal is beneficial for moisture evaporation in internal layers of bamboo, and it also relieves internal stresses of bamboo, leading to improved stability of the quality of bamboo (Anokye *et al*. 2014).

Boiling and filling

Because of its high sugar content, the raw bamboo was subjected to boiling in hot water for 2 h to improve the resistance to decay and bacterial growth. Furthermore, the bamboo sections were boiled in a mixed solution composed of 0.8% sodium chloride and 1% acetic acid, at atmospheric pressure. Boiling is considered to be an effective way to dissolve a portion of the present organic substances such as starch, sugar, and protein. After the initial boiling, the bamboo sections were then boiled again and filled with a mixed solution of 41.5% alum and 30% polyethylene glycol for 3 h, at steam temperature of 100 to 200 °C and a pressure of 0.1 to 1.6 MPa. The filling of alum and polyethylene glycol into the intercellular space and parenchyma tissue of the bamboo effectively prevented the entire section from cracking during the subsequent drying and pressing.

Moisture content, density, and dry crack

The moisture content and density were tested according to GB/T 15780 (1995). The dry crack rate was tested manually.

Regular polygon milling and finger joints

To assemble bamboo units conveniently, the dried bamboo was milled into regular polygon faces with a dedicated device developed by the authors. In the present work, regular hexagon faces were combined based on cellular paratactic arrangement rules.

The quantitative value for the regular polygonization degree is 60 to 80%. The surface roughness was measured using a surface roughness meter according to GB/T3324 (1995). The surface roughness (Ra) of each polygon face was less than 80 μm. Representative hexagon-face bamboo specimens are shown in Fig. 1.

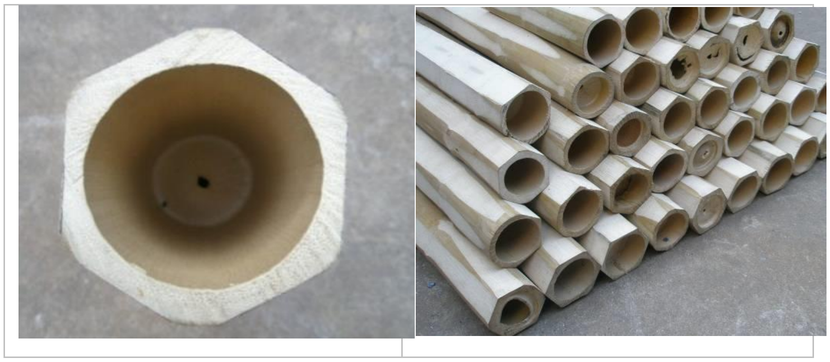

Fig. 1. Regular polygonization of original bamboo

To allow for longitudinal expansion, the polygonized bamboo units were then milled into finger joints on both ends of each segment, as a self-dedicated device performed the milling. It is worth noting that the finger joints should avoid the bamboo nodes, because of the fragility in their intense vascular tissue. Each designed finger joint had a length of 12 to 15 mm, and a slope of 1:8. The tooth top in these finger joints had a width and space of 0.6 and 3.8 mm, respectively. The milled tenon and finger joints are shown in Figs. 2a and 2b, respectively.

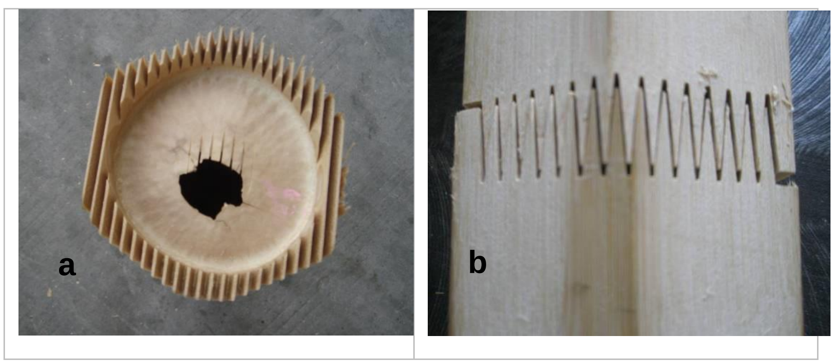

Fig. 2. (a) Mill tenon and (b) finger joint

Gluing and assembling

Bamboo sections are reasonably able to reach any destined length through finger joints. Prior to assembly, adhesive was manually coated at 300 g/m² spread level on the finger joints. The joints were glued under end pressure, which ranged from 8 to 12 MPa, created by a dedicated special-purpose longitudinal finger-jointer device. The fitness ratio of the finger joints was in the range of 0.1 to 0.2 mm.

The reorganized GPEHB were assembled based on the finger-jointed bamboo sections, performed by a dedicated device. Approximately 250 g/m^2 of adhesive was manually coated on the adjacent surfaces. The assembled specimens were maintained in the special mold, under 6 MPa of pressure, at room temperature for 20 h. Finally, the cross section of GPEHB was displayed into a honeycomb-shaped arrangement (Fig. 3a), which has been reported as a naturally strong and well-designed structure. In this work, the GPEHB consisted of 14 basic units, with lengths more than 5 m. The maximum GPEHB produced in our lab has the desirable dimensions of 6 m × 400 mm × 300 mm, as shown in Fig. 3b.

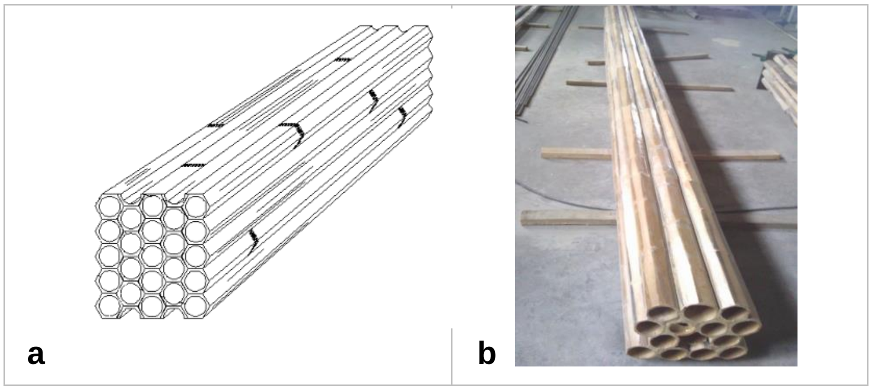

Fig. 3. GPEHB (a) Honeycomb-shaped arrangement; (b) final product

Mechanical properties

The mechanical properties of GPEHB were tested in the Engineering Testing Center of the Hunan University of Science and Technology, China. The tests were carried out according to Chinese national standard GB50005 (2003) and tested under four-point loading according to ASTM D4761-02a (2002). The mechanical properties, including the modulus of elasticity (MOE), was examined using 50 KN bending and YE-5000 hydraulic compression testing machines supplied by Jinan Fang Chen Instrument Equipment Co., Ltd. (China). For each condition, more than three samples were tested, and the average value was obtained.

Mechanical properties were tested according to GB/T 50344 (2004).

Heat conductivity coefficient

The heat conductivity coefficient of GPEHB was tested using a JW-III heat flow thermal conductivity meter (Beijing Dongfangaoda Instrument and Equipment Co., Ltd., China). As shown in Fig. 4, the examination meter has two parallel steel panels, which maintain a constant temperature.

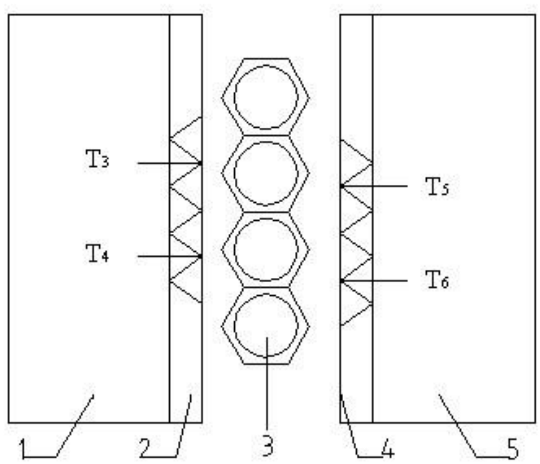

Fig. 4. Symmetrical arrangement of single sample and double heat flux. (1) Hot plate, (2) Hot plate heat flow meter, (3) GPEHB samples, (4) Cold plate heat flow meter, (5) Cold plate

The test area between panels, including test specimens, was exposed to the steady heat flow. Measurement of the thermoelectric potential (mv1 and mv2) from the hot and cold plate heat-flow meters, along with the surface temperatures (monitored by thermocouplers T3, T4, T5, and T6) ensure the calculation of the thermal resistance (R).

If the thickness of GPEHB samples is determined, the heat conductivity coefficient λ of the tested specimens can be precisely calculated. Prior to testing, the massive GPEHB specimens were cut into 10 cm × 10 cm test pieces and conditioned at 50% relative humidity for more than 24 h. The hot and relatively cool steel plates were set to temperatures of 60 and 30 °C, respectively. The tests were conducted at room temperature (25 to 30 °C), and the relative humidity was 20%.

Heat conductivity coefficients were tested according to GB/T 10295 (2008).

RESULTS AND DISCUSSION

Density and Crack Ratio of Drying after Boiling and Filling

The moisture content of the reorganized unit had an effect on the mechanical strength of the bamboo composite material. If the moisture content was too high, the materials suffer from moisture expansion and drying shrinkage, and the mechanical properties will be degraded to different extents. After boiling, filling, and subsequent drying, the moisture content of the basic bamboo units was greatly reduced (Table 1). The average moisture content was 13.4%, which approaches the equilibrium moisture content of bamboo.

The density of dried bamboo, lacking treatment, was 0.63 g/cm^3. The density of dried bamboo after boiling and filling was 0.68 g/cm^3, an increase of 8% in comparison to bamboo not subjected to boiling and filling. The results indicate that boiling and filling contribute to improving the density of the original bamboo. As a consequence, the improvement in density has a positive effect on the enhancement of strength and stability in the resulting GPEHB material as a large-scale structure in outdoor utilization. It should be noted that the crack ratio of the treated bamboo unit was reduced by 80% when compared to untreated bamboo, which has a high crack ratio of 24%. Crack ratio was manually calculated. The cracks that occur during drying are considered as a negative factor, potentially leading to a dramatic decrease in the mechanical strength of the recognized bamboo materials, particularly in its original state. In short, the pretreatment of boiling and filling on the bamboo unit helps to reduce the moisture content and crack ratio of the original bamboo unit, which will benefit its mechanical strength .

Table 1. Main Parameters of Original Bamboo With or Without Drying and Boiling Treatments

Sample	Moisture content (%)	Density (g/cm^3)	Dry crack rate (%)
Boiled and filled	13.39	0.68	5%
Control	13.35	0.63	24%

Regular Hexagonal Degree of Basic Bamboo Units

It is essential to define the performance index of the regular hexagon processed bamboo which will be called regular hexagonal degree. It can be clearly seen in Fig. 5 that the regular hexagonal degree is the ratio of L2 to L1, L2 is the length of the overlap straightline side of the cross-section of the hexagonal bamboo unit, and L1 is the length of the radius of a circle just large enough to enclose the cross-section of hexagonal bamboo unit.

Regular hexagon processing requires the following: 1) the cross sections of the bamboo in the same group have the same range, which has an average diameter deviation of 10 mm; 2) the regular hexagonal degree γ is not less than 40%; and 3) the optimally determined regular hexagonal degree is 60 to 80%. In this case, the regular polygonization degree of the bamboo unit processed during the testing period, through regularly polygonized face milling, was 72.70 to 84.48%. The average regular polygonization degree was 77.13%, with a standard deviation of 0.065. The regular polygonization degrees in these bamboo units were consistent, which is in accordance with the regular hexagonal degree determined in an optimal design.

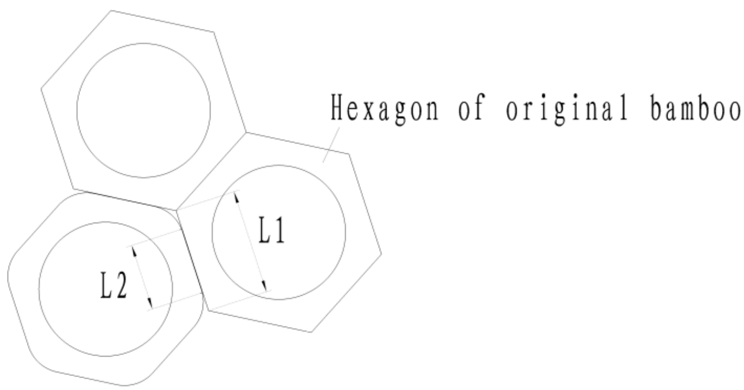

Fig. 5. Diagram of bamboo unit hexagon stitching

Mechanical Properties

The experiments used 30 samples for 7 units and 30 samples for 14 units, and the mean data for major GPEHB test parameters were acquired, as follows. As shown in Table 2, the maximum compression load of GPEHB (7 units, surface area of 495 cm^2, loading rate of 0.5 kN/min) was 170.5 kN. Another GPEHB specimen (14 units, surface area of 982 cm^2, loading rate of 0.5 kN/min) was capable of a loading compression of 493.5 kN, which meets the requirement for the strength grade of TC12 design value specified in the Chinese national Standard GB50005 -2003. On the contrary, the bending strength, as shown in Table 3, was relatively lower than the maximum compression strength. The bending load of GPEHB (7 units, surface area of 495 cm^2) was 12 kN, while the bending load of GPEHB (14 units, surface area of 495 cm^2) was 37 kN. It follows that the material can be used as beam structure material through the improvement of the bonding performance, reorganization method.

Table 2. Mean GPEHB Compression Test Parameter (parallel to the grain)

Category	Sample Length (m)	Mean Inside Diameter of Single Bamboo (mm)	Mean Outside Diameter of Single Bamboo (mm)	Total Number of Bamboos	Total Compression Area (mm^2)	Maximum Load (kN)
7 Units	2.05	84	96	7	15120	170.5
14 Units	2.53	84	96	14	30240	493.5

Table 3. Mean GPEHB Bending Test Parameter (parallel to the grain)

Category	Sample Length (m)	Mean Inside Diameter of Single Bamboo (mm)	Mean Outside Diameter of Single Bamboo (mm)	Total Number of Bamboos	Total Loading Area (mm²)	Maximum Load (kN)	Mid-span Maximum Displacement (mm)
7 Units	3.14	84	96	7	15120	12.0	110
14 Units	2.57	84	96	14	30240	37.0	50

Fig. 6. Transverse bending loading failure of GPEHB

When the compressive and bending properties of GPEHB were tested, practical application conditions were simulated. It was found that the advantages of the compressive property of GPEHB are usually obvious when it is used as a building material. However, the bending strength must be improved through gluing or physical strengthening, so as to meet the mechanical property requirements for building materials.

It was found that after the bending tests for GPEHB, severe delamination splitting appeared for fibers near the glue interfaces between the polygonization faces. However, the longitudinal finger joints were not damaged. The main reason is that the bending modulus and elastic modulus of each GPEHB units are different, due to the variability in the bamboo units. Furthermore, some units even drastically differ. When reorganization units are subject to the same bending load, the deformation amounts are different, resulting in the layering of the glue interfaces. The glue breaking strength of the polygonization faces is less than that the strength of the individual units, causing a reduction in structural strength of GPEHB, lessening its performance. The gluing property for the polygonization faces has important implications for GPEHB. Improving the glue breaking strength, as well as the horizontal (between polygonization faces) strength of GPEHB, is a problem that must be resolved during the expansion application (Figs. 6 and 7).

During the compression test perpendicular to grain for parallel to the grain, the bamboo units with defects in their finger joints were first destroyed. To be exact, the finger joint of the GPEHB reconstruction unit fractures and breaks from inside to outside, because the relative strength of the finger joint in the longitudinal direction is lower. Therefore, the compression strength parallel to grain of GPEHB can be improved if the finger joint gluing strength is improved.

Table 4. Comparison of GPEHB Unit Physical Properties with Common Structural Material (Lin and Fu 2008)

Type	Bending strength (MPa)	Parallel-to-grain compression (MPa)	Overall density (g/cm^3)
GPEHB unit	73.15	55.22	0.24
Glued laminated bamboo	125.44	59.93	1.00
Pinus sylvestris lumber	68.50	32.40	0.48

According to ISO 22157-1 (2004) (E) and ISO 22157-2 (2004) (E), the study tested the main mechanical performance of GPEHB units and several common materials. As Table 4 shows, the bending strength of the GPEHB unit was 73.15 MPa, which is higher than that of *Pinus sylvestris* lumber and less than glued laminated bamboo. The GPEHB unit parallel-to-grain compression was 55.22 MPa, also higher than that of *Pinus sylvestris* lumber, and below that of glued laminated bamboo. The overall density of the GPEHB unit was 0.24 g/cm^3, 76% lower than glued laminated bamboo, and 50% lower than *Pinus sylvestris* lumber.

The low density of GPEHB can be attributed to the internal structure of the material, which leads it to be a lightweight, high quality load-bearing material. Relative to glued laminated bamboo and *Pinus sylvestris* lumber, GPEHB has good mechanical properties, such as bending strength, parallel-to-grain compression, and excellent load performance in quality of unit.

Heat-conducting Property

The heat conductivity coefficient of GPEHB was 0.25 W/mK, the heat conductivity coefficient of concrete cement was 1.63 W/mK, and the heat conductivity coefficient of steel was 14.7 W/mK. Compared with other building materials such as stone, brick, concrete, and steel (which are non-renewable), GPEHB is a good kind of green building material. All of its basic mechanical performance indexes conform to the JIS A5905 (2003) thermal insulation wallboard standards. Foamed materials, such as polyethylene, can be added to the bamboo to be used as fine thermal insulation materials (Fig. 7).

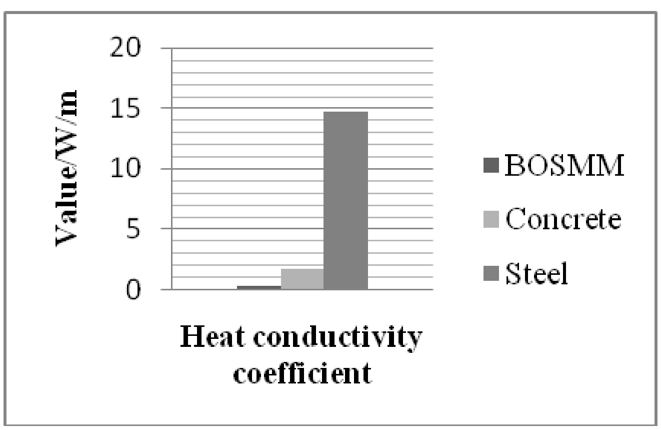

Fig. 7. Heat conductivity coefficient ratio among three kinds of conventional building material including GPEHB

CONCLUSIONS

1. After the original bamboos are processed through the boiling and filling method, their average moisture content is about 13.4%, with a basic density of 0.68 g/cm³, and with a crack rate of 5%. In comparison with untreated bamboo, the density can be increased by 8% and the crack ratio of treated bamboo unit can be reduced by 80% after processing.
2. After the original bamboos are milled using a dedicated device, the regular polygons of the bamboo segments are formed, and the degree of regular polygon reaches 77.13%, which meets the production requirements.
3. The GPEHB unit bending strength is 73.15 MPa, and the parallel-to-grain compression is 55.22 MPa, which is higher than that of *Pinus sylvestris* lumber and below that of glued laminated bamboo. GPEHB unit overall density is 0.24 g/ cm³, 76% lower than glued laminated bamboo and 50% lower than *Pinus sylvestris* lumber.
4. When the adhesive quantity is 300 g/m², the pressure on the longitudinal end ranges from 8 to 12 MPa, the fitness ratio ranges from 0.1 to 0.2 mm, the length is 12 mm, and the testing piece length is 300 mm. After the bamboos are processed by longitudinal finger-jointers, the average maximum compressive load of the GPEHB reorganization units is 74.11 kN and the average maximum bending load is 7.42 kN. The average bending strength of GPEHB finger-joint reorganization units is 73.15 MPa, and the compression strength parallel to grain is 51.22 MPa.
5. The compressive strength for GPEHB (7 units) is 170.5 kN, while that of GPEHB (14 units) is 493.5 kN, which meet the requirements for the strength grade TC12 design value specified in GB50005 -2003. The bending strength of GPEHB (7 units) is 12 kN, while that of GPEHB (14 units) is 37 kN, which does not meet the requirements for the strength grade TC12 design value specified in GB50005 -2003. Therefore, GPEHB can be used as beam structure material with the improvement of bonding performance, reorganization method, and introduction of components.
6. The result indicates that GPEHB has the potential to serve as building material for beam and column, decorative material, furniture material, *etc*. It could replace structural timber, panels, furniture components, beams, column or other purpose they are suitable for.

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REFERENCES CITED

Anokye, R., Kalong, R. M., Bakar, E. S., Ratnasingam, J., Jawaid, M., and Awang, K. (2014). "Variations in moisture content affect the shrinkage of *Gigantochloa* *scortechinii* and *Bambusa vulgaris* at different heights of the bamboo culm," *BioResources* 9(4), 7484-7493.

Andrews, E. W., Gioux, G., and Onck, P. (2001). "Size effects in ductile cellular solids. Part II: Experimental results," *International Journal of Mechanical Sciences* 43(3), 701-713. DOI: 10.1016/S0020-7403(00)00043-6

ASTM D4761-02a. (2002). "Standard test methods for mechanical properties of lumber and wood-base structural material," ASTM International, West Conshohocken, PA.

Chen, F., Jiang, Z., Wang, G., Shi, S. Q., and Liu, X. (2013). "Bamboo bundle corrugated laminated composites (BCLC). Part I. Three dimensional stability in response to corrugating effect," *The Journal of Adhesion* 89(3), 225-238. DOI: 10.1080/00218464.2013.739044

Fu, W., and Zhou, J. (2007). "Bamboo original state multiparty recombinant material and the manufacturing method," *China Patent* 200710179001.7.

Fu, W., and Zhou, J. (2011). "Prestress structural material formed by reorganization with polygonal original bamboo and the manufacturing method," *U.S. Patent* US20110151172 A1.

GB 50005. (2003). "Code for design of timber structures," Chinese National Standardization Management Committee, China.

Hohe, J., and Becker, W. (2000). "A mechanical model for two dimensional cellular sandwich cores with general geometry," *Computational Materials Science* 19(1-4), 108-115. DOI: 10.1016/S0927-0256(00)00145-2

ISO 22157. (2004). "Bamboo - Determination of physical and mechanical properties - Part 1: Requirements," International Organization of Standardization, Geneva, Switzerland.

Jiang, Z., Chen, F., Wang, G., Liu, X., Shi, Q. S., Yu, Z, and (2013). "Bamboo bundle corrugated laminated composites (BCLC). Part II. Damage analysis under low velocity impact loading," *BioResources* 8(1), 923-932. DOI: 10.15376/biores.8.1.923-932

Li, X., Hu, N., and Li, H. (2011). "Study on preparation technology of bamboo mat/bamboo particle board for new construction formwork," *Journal of Central South University of Forestry and Technology* 31(1), 113-116.

Li, Y., and Wang, J. (2007). "Modern material technology of bamboo and its application in architectural design," *Urbanism and Architecture* 8, 81-82.

Lin, L. Y., and Fu, F. (2008). "End pressure and fitness ratio for mini-finger jointing," *Journal of Beijing Forestry University* 30(2), 138-142.

Ma, H. X. (2009). *Interface Gluability and its Affecting Factors of Bamboo/poplar Composite*, Ph.D. thesis, Chinese Academy of Forestry, Beijing.

Nugroho, N., and Ando, N. (2000). "Development of structural composite products made from bamboo, I: Fundamental properties of bamboo zephyr board," *Journal of Wood Science* 46(1), 68-74.

Nugroho, N., and Ando, N. (2001). "Development of structural composite products made from bamboo Ⅱ: Fundamental properties of bamboo lumber," *Journal of Wood Science* 47(3), 237-242.

Qin, L., and Yu, W. (2009). "Status and prospects of reconstituted bamboo lumber," *World Forestry Research* 22(6), 55-59.

Serrano, E., and Enquist, B. (2005). "Contact-free measurement and non-linear finite element analyses of strain distribution along wood adhesive bonds," *Holzforschung* 59(6), 641-646. DOI: 10.1515/HF.2005.103

Shiji, Y., Muramoto, Y., and Shimizu, N. (2007). "AC breakdown properties of bamboo pulp-ice composite system at cryogenic temperature," *IEEE Transactions on Dielectrics and Electrical Insulation* 14(2), 296-301.
Sun, Z.-Y., Tang, Y.-Q., Iwanaga, T., Sho, T., and Kida, K. (2011). "Production of fuel ethanol from bamboo by concentrated sulfuric acid hydrolysis followed by continuous ethanol fermentation," *Bioresource Technology* 102(23), 10929-10935. DOI: 10.1016/j.biortech.2011.09.071.
Vogtlander, J., van der Lugt, P., and Brezet, H. (2010). "The sustainability of bamboo products for local and Western European application: LCAS and land-use," *Journal of Cleaner Production* 18(13), 1260-1269. DOI: 10.1016/j.jclepro.2010.04.015
Yao, L. H. (2010). *Study on the Physical and Chemical Properties of Interface of Moso Bamboo/Chinese Fir Composite*, Ph.D. thesis, Chinese Academy of Forestry, Beijing.
Zhang, H., and Du, F. (2007). "Research and development of production technology of bamboo wafer board and oriented strand board based on biological characteristics and timber adaptability," *Journal of Bamboo Research* 26(2), 46-51.

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